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# ENGINEERING PROPERTIES OF CLAYEY SOIL STABILIZED WITH LIME

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**ABSTRACT**

Kaolin soil represents the soft clay soil with a depleted bearing capacity and an elevated compressibility level. Thus, in order to hold up civil structures, the bearing capacity of kaolin soil needs to be raised. Several soil improvement procedures are currently available. These include soil replacement, preloading, corduroy and chemical stabilization. However, as these procedures are harmful to the environment, efforts to achieve soil stabilization ought to make use of materials that are environmentally friendly. The utilization of industrial waste that does not have a negative impact on the environment would represent a significant step forward in this area. Among the most frequently employed procedures to achieve soil stabilization is the utilization of a binder such as lime. This study puts forward an array of laboratory investigations to assess the influence of lime on the compressibility and swelling traits of soil. According to the findings, the liquid limit and plasticity index of soil is reduced with the introduction of lime. Pozzolanic reactions transpire due to the siliceous and aluminous nature of the material which has a negligible cementation value and is made up of large particles. This circumstance culminates in a reduction of the liquid limit. With a 9% application of lime, an elevation in the liquid limit was observed (a decrease in other reaction materials). This is attributed to the excessive presence of lime. The optimal water content rose from 20% to 23% with a 5% application of lime. The stabilizer content (lime) reduces the maximum dry density from 1.63 to 1.585 g/cm3. Lime content enhances the compressibility of soft clay by lowering the coefficient of volume compressibility (mv) reduces with increasing stabilizer content and the optimum percent for lime. This is a result of the reaction between lime and soil.

**Keywords:** kaolin, clay, stabilization, lime, compaction, compressibility.

## INTRODUCTION

The usage of local soils in construction schemes is currently in the limelight due to escalations in the prices of premium materials. However, local soils are frequently saddled with inappropriate engineering traits that include a poor workability level and low strength. These setbacks represent major stumbling blocks in efforts to reduce costs in the field of construction through the utilization of local soils. Lime, cement, fly ash, lime–cement–fly ash admixture, emulsified asphalt, goofier and polymer among others, are commonly utilized as additives to enhance the geotechnical traits of soil. A substantial number of stabilization techniques for raising the engineering qualities of soil are also currently available. These include compaction, consolidation, grouting, Admix Turing, reinforcement and thermal techniques. For the most part, soil characteristics are altered to enhance the shear strength, loading capacity, stability, and the capacity for deformation management. The determination of an additive and its impact is dependent on the nature of the soil in question and the field circumstances. Hence, prior awareness on the mechanical behaviour of treated soil significantly influences the determination of an appropriate stabilizer.

Procedures to improve the engineering traits of soil that involve the introduction of chemicals such as cement, fly ash, lime, or a blend of these chemicals, usually change the physical and chemical characteristics of the treated soil. Two principal mechanisms are involved in the enhancement of soil properties through the utilization of chemicals (Asgari, Baghebanzadeh Dezfuli *et al.* 2015);

1. Enlargement of particle size attributed to cementation, rise in shear strength, alteration in plasticity traits, and a decrease in the odds for deformation.
2. Absorption and chemical binding of moisture that will pave the way for compaction.

For many years, researchers in this domain have concentrated their efforts on soil stabilization through the utilization of a range of additives including lime, cement, fly ash, industrial waste products, potassium nitrate, calcium chloride, silica fume and phosphoric acid (Basma and Tuncer 1991, Sherwood 1993, Bell 1996, Miller and Azad 2000, Harichane, Ghrici *et al.* 2011, Yilmaz and Ozaydin 2013, Fattah, A'amal *et al.* 2015, Fattah, Al-Saidi *et al.* 2015)

Soil stabilization is an economical and environmentally friendly process for altering the mechanical and chemical traits of soils through pozzolanic reaction for the purpose of enhancing their engineering qualities (Cuisinier, Auriol *et al.* 2011, Harichane, Ghrici *et al.* 2011). Chemical stabilization also plays a crucial role in the treatment of soil systems in relation to the construction of dams, canals, river levees and more than. However, studies on the effects and effectiveness of lime treatment on the consolidation behaviour of soil are exceedingly restricted. Compressibility is among the most significant properties of soil in the context of engineering construction. This feature is crucial for a wide variety of geotechnical applications that include dam projects, foundations and embankment schemes. Soil compressibility is determined through what is known as a consolidation procedure. This is a process that involves the extruding of water particles and voids through the application of loads within a defined time frame. The time rate of consolidation is in relation to the volume of air present and the permeability of the soil. In a situation where the soil is not totally saturated, partial consolidation will occur almost instantly due to the expulsion of residual air or water within the soil particles. The deformation of soil particles results in settlement of the soil mass which facilitates an assessment of the volume variation behaviour of a soil.

The compressibility level is determined through a compression index (Cc) parameter. This is the slope of the line attained through the void ratio versus the effective vertical stress curve (Nalbantoglu and Tuncer 2001, Tiwari and Ajmera 2011). Although many investigations have focused on the impact of soil stabilization on the compressibility of soil, the outcomes from these investigations appear unclear and more in-depth studies ought to be in the pipeline. Thus, in view of the need to comprehend the consolidation behaviour of soil and the dearth of information on the effects of chemical stabilization on soil compressibility, this study offers an assessment on the influence of lime on the consolidation traits of soil.

Although lime is among the earliest additives utilized for enhancing the engineering properties of soil, its popularity has remained intact. The four primary additives used for geotechnical construction which are based on lime are hydrated high calcium lime Ca(OH)2, calcitic quick lime CaO, monohydrated dolomitic lime Ca(OH)2 MgO, and dolomitic quick lime CaO MgO. Lime treatment is beneficial to the construction industry for the following reasons (Mallela, Harold Von Quintus *et al.* 2004). To begin with, a drop in the liquid limit and an elevation of the plastic limit leads to a substantial decrease in the plasticity index. And a decrease in the plasticity index paves the way for a raised workability level of the treated soil. Secondly, the chemical reaction that occurs between soil and lime consequentially leads to a decrease in water content. Also, while the introduction of lime raises the optimum water content, it also serves to lower the maximum dry density. And lastly, an instant rise in strength leads to the generation of a supportive platform for the movement of heavy machinery.

The objective of this paper is stabilize kaolin clay with lime. The effect of lime on the Atterberg limits, compaction and compressibility is investigated.

## EXPERIMENTAL WORK

### Material Used

Kaolin clay, which is frequently utilized in the production of ceramics, tooth paste, fodder, paper and dye, was used as untreated soil, Figure-1. As it loses moisture very gradually and is easily managed, kaolin clay has a wide range of uses. It is made up of repeated layers of elemental silica-gibbsite sheets with each layer measuring roughly 7.2 Aº in thickness. The layers are bound together by hydrogen bonds and secondary valence forces (Murthy 2002). The kaolin group, which is a hydrous alumina-silicate, has the general chemical make-up formula Al2(Si2O5)(OH)4. Information on the physical properties and chemical composition of kaolin clay utilized for this investigation are available in Tables-1 and 2 respectively.

The lime selected for this research is an industrial hydrated lime, Figure-2. This lime is deemed applicable as a neutralizing agent for water and sewage treatment, as a binder in mortars, as a soil stabilizer, and as a means for maintaining alkaline conditions during the processing of minerals. Hydrated high calcium lime, Ca (OH)2, which is accessible locally, is an established stabilizing agent. In comparison to other types of limes, hydrated lime has proven to be superior in the area of soil stabilization. This is attributed to its trouble-free usage and fine particle size which allows for easy mixing with soil (Amiralian 2013). To complete its list of benefits, hydrated lime is also less of a safety hazard. Table-3 displays the chemical properties of lime utilized for this research.

### Laboratory Testing

Experiments were conducted to determine the physical and chemical traits of clayey soil in their natural form. Subsequently, tests were executed on clayey soil samples mixed with different percentages of lime. The tests took into account Atterberg limits, specific gravity, compaction and consolidation.

### Preparation of Soil Mixtures for Testing

Prior to amalgamation, the clay soil samples were dried in an oven with the temperature set at 100 Co. To prepare the mixtures, kaolin soil S300 and lime were blended under dry conditions. The quantity of lime varied from 3%, 5%, 7% and 9% of the total dry weights of the kaolin-lime mixture. Kaolinite was air-dried and deposited in plastic containers for storage in the laboratory. When required, it was removed from the containers and the determined amount by weight was merged with a prearranged quantity of lime through the utilization of a hand mixer equipped with speed control. A thorough mixing is necessary for the uniform distribution of moisture. The pace of the mixer was held constant during the mixing process. Subsequent to five minutes of mixing, water was gradually added to the mixture. The quantity of water added matched the optimum moisture content of the soil and lime mixture which was determined through compaction testing.

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**Figure-1.** Kaolin soil.

**Figure-2.** Lime.

**Table-1.** Physical properties of Kaolin used in the study.

| Test | Value | Specifications |
|---|---|---|
| Consistency Limits: | | |
| • Liquid limit, L.L, % | 39.50 | BS 1377:1975, Test 2(A) |
| • Plastic limit, P.L, % | 28 | BS 1377:1975 Test 3. |
| • Plasticity index, P.I, % | 11.50 | |
| | | |
| Specific gravity | 2.64 | BS 1377:1975, Test 6 (B) |
| | | |
| Soil Compaction: | | |
| • OMC (Optimum Moisture Content), | 20% | BS 1377:1975, Test12 |
| • MDD (Maximum Dry Density), $G/cm^3$ | 1.63 | |
| | | |
| Classification According to Unified Classification System | ML | |

**Table-2.** Chemical composition of Kaolin.

| Component | Results |
|---|---|
| $Sio_2$ % | 66.11 |
| $Al_2O_3$ % | 19.25 |
| $K_2O$ % | 2.850 |
| MgO % | 1.230 |
| $Fe_2O_3$ % | 0.730 |
| $TiO_2$ % | 0.610 |
| $P_2O_5$ % | 0.410 |
| $ZrO_2$ % | 0.090 |
| CaO % | 0.080 |
| BaO % | 0.040 |
| SO3 % | 0.030 |
| Rb2O % | 0.010 |
| ZnO, p.p.m | 49.00 |
| Y2O3, p.p.m | 34.00 |
| CuO, p.p.m | 29.00 |
| NiO, p.p.m | 24.00 |
| Nb2O5, p.p.m | 22.00 |
| Ga2O3, p.p.m | 16.00 |

**Table-3.** Chemical composition of lime.

| Parameter | Results |
|---|---|
| CaO, % | 75.77 |
| MgO, % | 3.700 |
| SiO2, % | 0.310 |
| P2O5, % | 0.200 |
| Fe2O3, % | 0.160 |
| Al2O3, % | 0.120 |
| Cl, % | 0.040 |
| K2O, % | 0.030 |
| SrO, % | 0.030 |
| MnO, % | 0.030 |
| SO3, % | 0.020 |
| TiO2, % | 0.010 |
| ZnO, p.p.m. | 95.00 |
| CuO, p.p.m. | 46.00 |
| ZrO2, p.p.m. | 3.000 |

**Atterberg Limits**

The purpose of carrying out Atterberg limits tests is to calculate and recognize the plasticity scale in a mathematical context. This is crucial particularly when it concerns clay as its moisture content corresponds with plastic consistency. This test was executed on kaolin clay with a particle dimension lesser than 0.42 mm (passing sieve No. 40). Atterberg limits were further separated into three distinct experiments, namely, liquid limit (WL), plastic limit (WP) and shrinkage limit (WS) tests. The liquid limit test was carried out in compliance with the BS1377 Part 2:1990:4.3 with the utilization of the cone penetration technique, while the plastic limit test was executed in accordance with the BS1377 Part2:1990:5.3. The mathematical disparity between liquid limit and plastic limit is known as the plasticity index (Astm 2003).

**Specific Gravity**

The specific gravity of kaolin was computed through a small pycnometer test. The samples with predetermined masses were placed in a small pycnometer which had been half-filled with distilled water. The small pycnometer was then positioned within a vacuum chamber which proceeded to remove the air present in the sample which is made up of a mixture comprising the material and distilled water. The sample was left undisturbed for a day, following which distilled water was added into the pycnometer to the brim (D854-02 2002).

**Compaction Test**

A standard compaction test was conducted to study the impact of varying combinations of lime on kaolin clayey soil behaviour. Details on the standard compaction test procedure are available in the ASTM (ASTM D 698-00, method A) and (ASTM D 1557-00, method A). These tests were conducted to establish the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. Utilizing the standard Proctor effort, the samples were compacted in a 105 mm-diameter mould. The dry unit weight and moisture content of each sample were determined through the achieved unit weight at the optimum moisture point. This was ascertained by the intersection of slopes derived from the wet-side and dry-side soil of the compaction curve from a minimum of five compaction tests.

**One-Dimensional Consolidation Test**

A sequence of one-dimensional consolidation tests was executed for the purpose of studying the influence of lime on the compressibility of soil. The consolidation test as depicted in the ASTM D 2435-96 was utilized for the saturated and partially saturated subsamples. This test serves to ascertain the extent and pace of volume decrease in relation to laterally restricted soil undergoing a range of vertical pressures. The outcomes will be examined in accordance with the “void ratio-effective stress curves” and “settlement-log time curves”.

To ensure a dependable outcome, the automatic consolidation device was employed. This device documents data on load, displacement and elapsed time at one second intervals. The samples were placed between two porous stones and filter paper which were positioned on the top and bottom of the samples, respectively. These samples were subjected to an initial seating load of 50 kPa with each succeeding load doubled until 400 kPa was arrived at. The period for each loading was between a minimum of 3 hours and a maximum of 24 hours. This time span is dependent on the preliminary data and software computation. The minimum time span necessary in relation to displacement for each loading was computed, following which the 100% primary consolidation was worked out. Earlier investigations revealed that tests with varying time spans for lime load increments on soil denote that the initial consolidation of lime samples was accomplished quicker than the assessed time span for each load increment (Harichane, Ghrici *et al.* 2011)

**Results of Tests**

This study forwards an explanation on the impact resulting from the application of varying percentages of lime on kaolin clayey soil. The outcomes from this investigation along with discussions are portrayed in the following segments.

**Effect of Lime on Atterberg Limits**

The Atterberg limits results regarding soil and lime combinations at varying percentages are exhibited in Figure-3. The reduction in liquid limit is a consequence of exchanges between the free calcium of the lime and the adsorbed cations of the clay mineral. This leads to a decrease in size of the diffused water layer encircling the clay particles. The decrease in size of the diffused water layer facilitates closer contact between the clay particles resulting in flocculation/agglomeration of these particles.

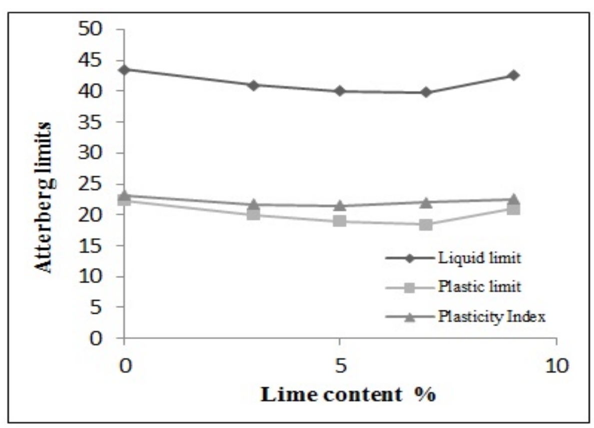


**Figure-3.** Atterberg limits of kaolin soil with different percentages of lime.

**Effect of Lime on Specific Gravity**

The Specific Gravities (GS) for untreated and treated soils were ascertained and plotted as displayed

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Figure-4. As can be observed, the specific gravity of the controlled sample rose from 2.64 to 2.72 at a lime content of 5%. This rise is attributed to the molecular reshuffling of the soil matrix due to the superior density of lime over that of kaolin soft clay. Further than this point, the specific gravity stayed invariable for the samples of stabilized soil holding 5% to 7% of lime. A reduction in specific gravity from 2.725 to 2.66 was observed in the samples of the soil stabilized with a lime content of 7% to 9%. The reduction in the specific gravity of soil as the lime content was raised is attributed to the low specific gravity of lime which is in the region of 2.3.

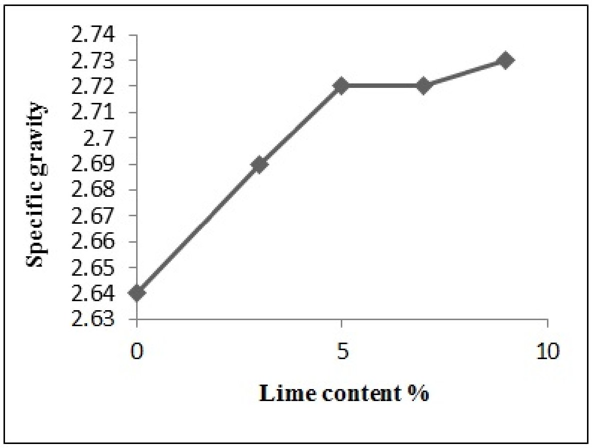


**Figure-4.**Specific gravity of kaolin soil with different percentages of lime.

**Effect of Lime on Compaction Characteristics**

Figure-5 displays the association between the dry density and water content with varying lime contents, Figure-6 portrays the influence of lime on the optimum water content, and Figure-7 exhibits the impact of lime on the maximum dry density.

It can be observed that as a result of a decrease in the parallel orientation to the clay particles at 6% L, the compactive effort was reduced (Figure-5). Figure-6 displays a rise in the optimum water content from 20% to 23% at a lime content of 5%. This rise, which persisted even though the surface area was decreased through flocculation and agglomeration, is attributed to the added fine contents to the samples which necessitate more water, and the free lime which requires additional water to initiate the pozzolanic reactions. It is likely that the elevated optimum moisture content with the introduction of lime can be attributed to water adsorption by lime. The tangible disparities in the maximum dry density and lime content validate the fact that a stabilizer material (lime) reduces the maximum dry density from 1.63 to 1.585 g/cm³. This is displayed in Figure-5. The reduced maximum dry unit weight can be put down to the substitution of soil by the lime in the mixture which possesses a comparatively lower specific gravity (2.3) than that of soil (roughly 2.64). This circumstance could also be traced to the coating of soil by lime. The resulting larger particles enlarge the voids and this leads to a reduced density of the soil (Bell 1996, Sharma, Swain *et al.* 2012) opined that the optimum addition of lime required for maximum alteration of soil is generally between 1% and 3% by weight. Additions beyond this point do not bring about any alteration in the plastic limit, but they do elevate the strength of the soil.

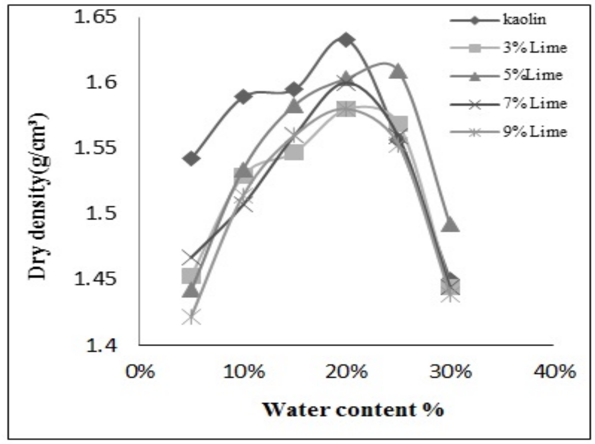


**Figure-5.** Water content-density relationships from compaction test on kaolin soil stabilized with different percentages of lime.

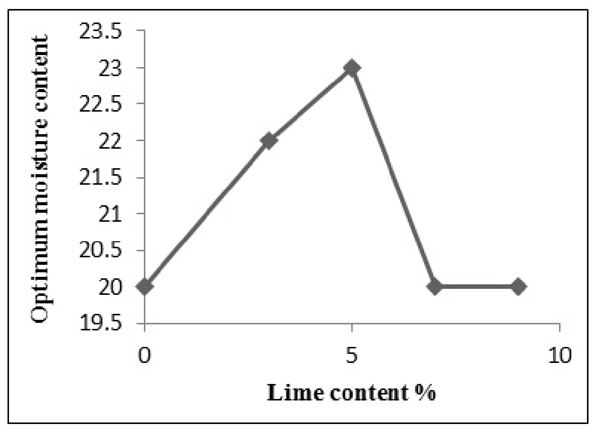


**Figure-6.** Effect of lime on the optimum moisture content**.**

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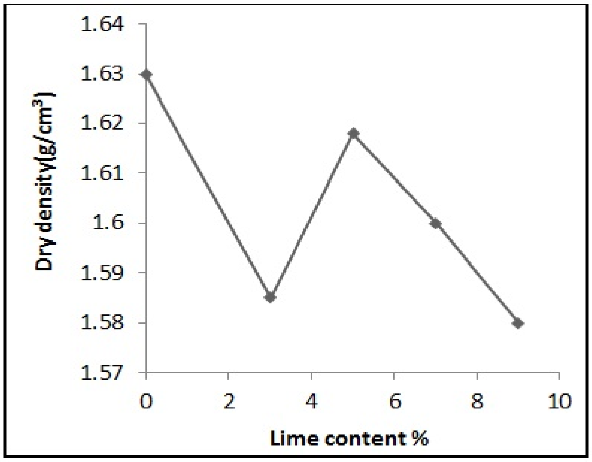


**Figure-7.** Effect of lime on the maximum dry density.

**Effect of Lime on Compressibility Characteristics**

Figure-8 shows the pressure-void ratio relationships for soils stabilized with different percentages of lime as obtained from consolidation test.

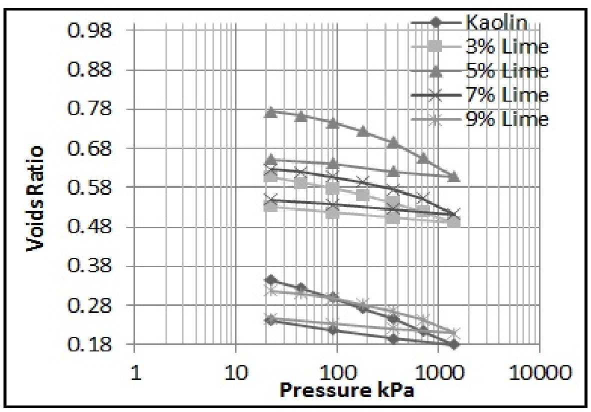


**Figure-8.**Effect of lime on compressibility characteristics.

- **Coefficient of Volume Compressibility (mv)**

The coefficient of volume compressibility, mv, is defined as the volume change per unit increase in effective stress for a unit volume of soil (Knappett 2012). The volume change may be expressed in terms of void ratio or specimen thickness. This parameter is very useful to estimate the primary consolidation settlement. Table-4 shows the results of coefficient of volume compressibility on lime. It can be noticed that the average coefficient of volume compressibility decreases with increasing the stabilizer content until 7%, the coefficient of volume compressibility increases at 7% and 9% as shown in Figure-9. This could probably be due to pozzolanic reaction taking place within the soil which in turn changes the soil matrix. The free calcium of the lime exchanges with the adsorbed cations of the clay mineral, resulting in reduction in size of the diffused water layer surrounding the clay particles. This reduction in the diffused water layer allows the clay particles to come into closer contact with one another, causing flocculation/agglomeration of the clay particles, which transforms the clay into a more silt-like or sand like material.

**Table-4.** Effect of lime content on the coefficients of volume compressibility (mv)(m2/MN).

| LoadkPa | Kaolin lime % | | | | |
|---|---|---|---|---|---|
| | 0 | 3% | 5% | 7% | 9% |
| 22.2 | 10.00 | 2.22 | 1.11 | 4.10 | 11.87 |
| 44.4 | 0.70 | 0.42 | 0.26 | 0.19 | 0.24 |
| 88.8 k | 0.39 | 0.20 | 0.22 | 0.16 | 0.21 |
| 177.6 | 0.23 | 0.13 | 0.14 | 0.10 | 0.13 |
| 355.3 | 0.12 | 0.07 | 0.09 | 0.07 | 0.08 |
| 710.6 | 0.07 | 0.04 | 0.07 | 0.04 | 0.05 |
| 1421.1 | 0.04 | 0.02 | 0.04 | 0.04 | 0.04 |
| Average | 1.65 | 0.442 | 0.275 | 0.671 | 1.802 |

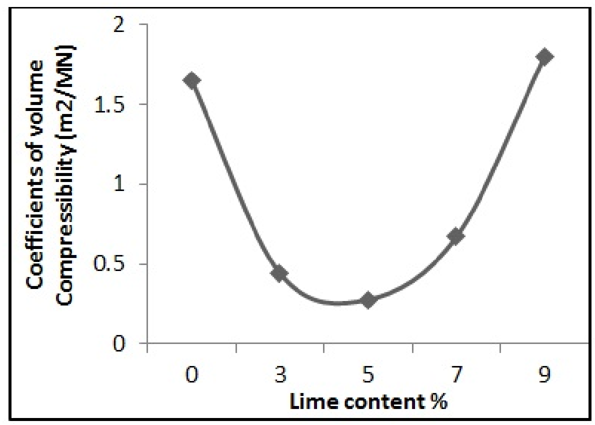


**Figure-9.** Effect of lime on compressibility characteristics.

**CONCLUSIONS**

During this investigation a series of experiments were conducted on kaolin clayey soil mixed with varying amounts of lime in order to recognize the traits of soils stabilized with this material. It was established that:

1) A reduction in the liquid limit and plasticity index was achieved through the introduction of lime. Pozzolanic reactions are attributed to (a) the presence of siliceous and aluminous materials which have negligible cementation capabilities and (b) large particles which result in a reduction of the liquid limit. With a 9% loading of lime, a rise in the liquid limit occurred due to the excessive lime content (a reduction occurred in other reaction materials).

2) The specific gravity level rose from 2.64 to 2.72 with a lime content of 5%. Further than this point, the specific gravity stayed invariable for the samples of stabilized soil holding 5% to 7% of lime. The specific gravity of the stabilized soil holding 7% to 9% of lime dropped from 2.725 to 2.66. This drop in specific gravity resulting from raised lime content is attributed

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to the low specific gravity of lime which is approximately 2.3.

3) The optimum water content rose from 20% to 23% with a 5% lime content. Lime as a stabilizer reduced the maximum dry density from 1.63 to 1.585 g/cm3.
4) Lime has the capacity to enhance the compressibility of kaolin clay through the reduction of the coefficient of volume compressibility (mv).
5) Due to lime-soil reaction, the optimum percentages were determined as 3% and 5% lime.

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